

Saepo Modi and Correlation among Statistical Methods for Measuring of Phenotypic Stability*Saepo Modi dan Korelasi antar metode Statistik untuk Mengukur Stabilitas Fenotipe*Sabam Malau^{1*}, Albiner Siagian², Maria Rumondang Sihotang³, Rosnawyta Simanjuntak⁴, N.D.M. Romauli Hutabarat⁵¹ Agroecotechnology Department, Agriculture Faculty, Universitas HKBP Nommensen, Jalan Sutomo 4-A, Medan 20234, Indonesia.² Public Health Department, Universitas Sumatera Utara, Jalan Abdul Hakim 1, Medan, Indonesia.³ Agribusiness Department, Agriculture Faculty, Universitas HKBP Nommensen, Jalan Sutomo 4-A, Medan 20234, Indonesia.⁴ Technology of Agriculture Product Department, Agriculture Faculty, Universitas HKBP Nommensen, Jalan Sutomo 4-A, Medan 20234, Indonesia.⁵ Food Science and Technology, Faculty of Agriculture, Universitas Sumatera Utara, Jalan Prof A Sofyan 3, Medan, Indonesia.*Corresponding author : sabam.malau@uhn.ac.id**ABSTRACT**

A stabile phenotype is desired. Many statistical methods are available to measure stability. So far, the choice of parameter of stability depended on the perception on the interaction of genotype and environment or ease of counting. The goal of this research was to study correlation among stability parameters. In total of 16 stability parameters were used in this research. Saepo modi (SM_{sp}) as a stability parameter was also used. Branch rust incidence, leaf rust incidence, and leaf rust severity on Arabica coffee were used as variables. This research result showed that none of the parameters of stability correlated significantly with all parameter of stability. It could be concluded that if someone want to use only one stability parameter, it is preferred to make use of regression and deviation from regression (D^2_i). In the case a researcher needs to use several of parameters of stability, Saepo modi (SM_{sp}) might be exercised.

Keywords: *genotypes, interaction, leaf rust, parameter***ABSTRAK**

Suatu fenotipe yang stabil yang diharapkan. Banyak metode statistik tersedia untuk mengukur stabilitas. Sejauh ini, pemilihan parameter stabilitas tergantung kepada persepsi tentang interaksi genotipe dengan lingkungan atau kemudahan perhitungan. Tujuan dari penelitian ini adalah untuk mengkaji korelasi antarparameter stabilitas. Sebanyak 16 parameter stabilitas digunakan pada penelitian ini. Saepo modi (SM_{sp}) sebagai suatu parameter stabilitas juga digunakan. Insiden karat cabang, insiden karat daun dan keparahan karat daun pada kopi Arabica digunakan sebagai variabel. Hasil penelitian ini menunjukkan bahwa tidak satupun dari parameter stabilitas berkorelasi signifikan dengan semua parameter stabilitas. Kesimpulan penelitian ini adalah jika seseorang ingin menggunakan hanya satu parameter stabilitas, ia

disarankan menggunakan regresi dan deviasi dari regresi (D^2_i). Dalam hal seorang peneliti ingin menggunakan beberapa parameter stabilitas, Saepo modi (SM_{sp}) dapat digunakan.

Kata kunci: *genotipe, interaksi, karat daun, parameter*

INTRODUCTION

Task of plant breeding is to create the best genotype with high quantity, quality and stability of production over a wide range of growth environment. Experiments over seasons and years must be carried out to test the stability of genotypes perfering certain phenotypes because rank of genotypes could be changed in differen environment due to interaction of genotype and enviroment. Test of stability was used in the important commodities such as barley (Sabaghnia et al., 2012), black spure (Khalil, 1984), Chenopodium spp (Bhargava et al., 2005), chili pepper (Syukur et al., 2014), durum wheat (Akcura et al., 2006), faba bean (Temesgen et al., 2015), field pea (Fikere et al., 2010), lentil (Dehghani et al., 2008), maize (Scapim et al., 2000), oilseed rape (Brandle and McVetty, 1988; Oghan et al., 2013), potato (Flis et al., 2014), rice (Purbokurniawan et al., 2014, Balakrishnan et al., 2016), rubber tree (Silva et al., 2014), sorghum (Adugna, 2008), sugar cane (Rea et al., 2017), sweet potato (Bacusmo et al., 1988), and vetch (Sayar et al., 2013).

The concepts of stability comprises dynamic and static stability. Dynamic stability of phenotype describes the ability of a genotype to increase its performance in better growth environment as well as to decrease its performance in worse growth condition. Static phenotypic stability explains the ability of genotype to perform constantly in various growth environment.

These concepts cause different statistical methods which are variance analysis (Roemer, 1917), regression (Finlay and Wilkinson, 1963), and non-parametric (Lin and Binns, 1988). Number of statistical methods for measuring stability increased (Becker and Leon, 1988).

Researchers use one or several of them based on the assumptions about the nature of G x E interaction as well as the need for an easy statistical calculation. It is needed to study correlation among those stability parameters. The objectives of this research was to study correlation among parameter of statistical methods for measuring of phenotypic stability. It was hypothesized that there was significant correlations among parameter of stabilities. Result of this research was expected to contribute to better understanding of analysis of stability as well as to help choosing appropriate parameter of stability.

MATERIAL AND METHOD

General forms of the observed value of k genotypes in n environments is presented in Table 2. X_{ij} is the observed value of the genotype i^{th} at the environment j^{th} . \bar{X}_i is the average performance of the genotype i^{th} at the environments j ($j = 1, 2, 3, \dots, n$). \bar{X}_j is the mean value of environment j^{th} across the genotypes i ($i = 1, 2, 3, \dots, k$). $\bar{X}_{..}$ is the general mean of all genotypes across the environments. $X_{..}$ is the grand total of the observed values.

Table 2. Hypothetical performance of k genotypes in n environments.

| Genotype | Code | Environment | | | | | Total | Mean |
|----------------|------|-----------------|-----------------|-----------------|-----|-----------------|-----------------|----------------|
| | | Envi-1 | Envi-2 | Envi-3 | . | Envi-j | n | |
| G1 | (1) | X ₁₁ | X ₁₂ | X ₁₃ | ... | X _{1j} | X _{1.} | $\bar{X}_{1.}$ |
| G2 | (2) | X ₂₁ | X ₂₂ | X ₂₃ | ... | X _{2j} | X _{2.} | $\bar{X}_{2.}$ |
| G3 | (3) | X ₃₁ | X ₃₂ | X ₃₃ | ... | X _{3j} | X _{3.} | $\bar{X}_{3.}$ |
| . | . | ... | ... | ... | ... | ... | ... | ... |
| . | . | ... | ... | ... | ... | ... | ... | ... |
| G _i | (i) | X _{i1} | X _{i2} | X _{i3} | ... | X _{ij} | X _{i.} | $\bar{X}_{i.}$ |
| Total | k | X _{.1} | X _{.2} | X _{.3} | ... | X _{.j} | X _{..} | |
| Mean | | $\bar{X}_{.1}$ | $\bar{X}_{.2}$ | $\bar{X}_{.3}$ | | $\bar{X}_{.j}$ | | $\bar{X}_{..}$ |

In this research, sixteen of the statistical methods for measuring the stability were used. They are based on the variance analysis (Roemer, 1917; Plaisted and Peterson, 1959; Plaisted, 1960; Wricke, 1962; Shukla, 1972; Francis and Kannenberg, 1978), regression (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; Perkins and Jinks, 1968; Hanson, 1970; Tai, 1971; Pinthus, 1973), and non-parametric (Lin and Binns, 1988; Kang, 1993).

Roemer (1917) proposed the deviation of the performance of the genotype from the genotypic mean ($x_{ij} - \bar{x}_{i.}$) as the indication of the environmental effect. The environmental variance of the genotype across the environments (s_i^2) is the measurement of stability of genotype. The genotype that shows the smallest s_i^2 is the most stable. The greatest stability is s_i^2 close to 0. The formula is

$$s_i^2 = \sum_{j=1}^n \frac{(x_{ij} - \bar{x}_{i.})^2}{k-1}.$$

Plaisted and Peterson (1959) suggested the mean variance component for pairwise GxE interaction (θ_i) as stability measure. The genotype with smaller θ_i is more stable. The formula is

$$\theta_i = \frac{k}{2(k-1)(n-1)} + \frac{\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2 + \sum_{i=1}^k \sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2}{2(k-1)(n-1)}.$$

Plaisted (1960) proposed the GxE interaction variance from the subset ($\theta_{(i)}$) as measurement of stability index of the genotype. The smaller the $\theta_{(i)}$ is, the more stable the genotype is. The formula is

$$\theta_{(i)} = \frac{-k}{(k-1)(k-2)/(n-1)} + \frac{\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2 + \sum_{i=1}^k \sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2}{(k-2)(n-1)}.$$

Wricke (1962) offered the idea that the genotypes contribute to the G x E interaction. The deviation of the genotypic effect ($x_{ij} - \bar{x}_{i.}$) from the environmental effect ($\bar{x}_{.j} - \bar{x}_{..}$) is the genotypic contribution to G x E interaction. The magnitude of this deviation is measured by the variance (W_i^2) termed ecovalence. The least W_i^2 (the highest ecovalence) is the most stable. The greatest stability is $W_i^2 = 0$. The formula is

$$W_i^2 = \sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2.$$

Shukla (1972) proposed stability variance (σ_i^2) which is the partitioning of the G x E sum of square into component for each genotype separately. The smaller σ_i^2 is, the more stable is. The most stable is genotype with $\sigma_i^2 = 0$. Negative value of σ_i^2 is equal to zero. The formula is

$$\sigma_i^2 = \frac{k}{(k-2)(n-1)} + \frac{\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2 + \sum_{i=1}^k \sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2}{(k-1)(k-2)(n-1)}$$

Francis and Kannenberg (1978) proposed relative variability as measurement of stability. Relative variability is represented by coefficient of variation (CV). Genotype with small CV is stable. CV close to 0 is the greatest stability. The formula is

$$CV_i = \frac{\sqrt{\sum_{j=1}^n \frac{(x_{ij} - \bar{x}_{i.})^2}{k-1}}}{\bar{x}_{i.}} \times 100\%$$

Finlay and Wilkinson (1963) proposed regression coefficient as measure of stability. The unity coefficient is $|b_i| = 1$. The genotype with $b = 1$ is the most stable. The formula is

$$b_i = \frac{\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})(\bar{x}_{.j} - \bar{x}_{..})}{\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2}$$

Eberhart and Russel (1966) defined the measure of stability as residual mean square of deviation from the regression (δ_i^2). The genotype with smaller δ_i^2 is more stable. The formula is

$$\delta_i^2 = \frac{1}{n-2} [\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2 - \beta_i^2 \sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2]$$

Perkins and Jinks (1968) proposed the regression coefficient (β_i) and the deviation from the regression line of each environment (ψ_i^2) as the measure of stability. A genotype is considered stable if $\beta_i = 0$ and $\psi_i^2 = 0$. The formula are

$$\beta_i = \frac{\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})](x_{ij} - \bar{x}_{i.})}{\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2},$$

and

$$\psi_i^2 = \frac{1}{n-2} [\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2 - \beta_i^2 \sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2]$$

Hanson (1970) proposed regression and deviation from regression (D_i^2) as stability measurement. The magnitude of the deviation of the genotypic effect ($x_{ij} - \bar{x}_{i.}$) from the environmental effect ($\bar{x}_{.j} - \bar{x}_{..}$) is calculated by using the minimum

observed simple coefficient regression b (b_m). The stable genotype does not deviate from the straight line. The genotype with smaller D_i^2 is more stable. The formula is

$$D_i^2 = \sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - b_m(\bar{x}_{.j} + \bar{x}_{..})]^2$$

Tai (1971) proposed the partitioning of GxE interaction into the linear response of genotype to the environmental effect (α_i) and the deviation from the linear response (λ_i) as measure of stability. The stability of genotype is characterize by α_i and λ_i . The genotype with ($\alpha_i = -1, \lambda_i = 1$) is the most stable, while the genotype with ($\alpha_i = 0, \lambda_i = 1$) has an average stability across environment. The genotype with (α_i, λ_i) < (0,1) performs an above-average stability, and genotype with (α_i, λ_i) > (0,1) shows a below-average stability. The formula are

$$\alpha_i = \frac{\{\sum_{j=1}^n (\bar{x}_{.j} - \bar{x}_{..})[(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]\}}{(MS_{Env} - MS_{Rep(Env)})/(kr)}, \text{ and}$$

$$\lambda_i = \frac{\left\{ \frac{\sum_{j=1}^n [(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]^2}{n-1} \right\} - \alpha_i^2 \left\{ \frac{\sum_{j=1}^n (\bar{x}_{.j} - \bar{x}_{..})[(x_{ij} - \bar{x}_{i.}) - (\bar{x}_{.j} - \bar{x}_{..})]}{n-1} \right\}}{[(k-1)MS_{Error}]/(kr)}$$

whereby MS mean square, MS_{Env} = MS of environment (location), $MS_{Rep(Env)}$ = MS of replication within environment, k = number of genotype, n = number of environment, MS_{Error} = MS of error (MS of pooled error), and r = number of replication.

Pinthus (1973) proposed the amount of the variation in genotypes that can be explained by the variation of environment i.e coefficient of determination (r^2) as stability measure. The coefficient of determination is calculated as the proportion of variation in genotypes from the total variation. The value of r^2 ranks is 0 (0%) to 1 (100%). The genotype with $r^2 = 1$ is the most stable. The formula is

$$r^2 = \left\{ \frac{\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})(\bar{x}_{.j} - \bar{x}_{..})}{\sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2} \right\}^2$$

Lin and Binns (1988) proposed the superiority of genotype over a series of environments (n) as measure of stability. The superiority of the genotype is the distance of the genotype performance from the maximal performance for that environment ($x_{ij} - \text{Max}_j$). The genotype with smaller variance of the superiority of the genotype averaged over all environments (P_i) is more stable. The formula is

$$P_i = \sum_{j=1}^n \frac{(x_{ij} - \text{Max}_j)^2}{2n}.$$

Kang (1993) proposed the sum of rank (κ_i) of the observed performance of the genotype (R_{ig}) with rank of of the genotype based on Sukla's stability variance (R_{is}) as measure of stability. Based on the genotype performance, the genotype with the highest performance is number 1. Based on the Sukla's stability variance, the genotype with the smallest Sukla's stability get number 1. The genotype with smaller κ_i is more stable. The formula is

$$\kappa_i = R_{ig} + R_{is}.$$

The authors of this paper propose the frequency as the basis for analysis which is termed *saepe modi* (Latin) abbreviated as SM. The best parameter of stability is the one that has the highest number of significant correlations (SM_{sp}) with other parameters. This method might be a nonparametric method.

Data of branch rust incidence, leaf rust incidence, and leaf rust severity on coffee leaves from coffee a field xperiment were used.

RESULT AND DISCUSSION

Analysis of stability parameters showed that none of the stability parameters were significantly correlated with all stability parameters in each phenotype (Table 1). Stability parameter D^2_i of Hanson (1970) for branch rust incidence correlated most frequently ($\text{SM}_{sp} = 11$) with other parameters of stability. However,

stability parameter ψ^2_i of Perkins and Jinks (1968) and CV_i of Francis and Kannenberg (1978) for leaf rust incidence had the highest frequency ($\text{SM}_{sp} = 11$). Stability parameter s^2_i of Roemer (1917), δ^2_i of Eberhart and Russel (1966), D^2_i of Hanson (1970), and r^2_i of Pinthus (1973) for leaf rust severity performed the same highest frequency ($\text{SM}_{sp} = 13$). The research result also showed that number of the frequency of the significant correlation among stability parameters were different if phenotypes were different (Table 1). The numbers ranged from 2 to 11, 4 to 11 and 1 to 13 for branch rust incidence, leaf rust incidence and leaf rust severity, respectively. Out of the total number of correlation over three phenotypes of each stability parameter (45), D^2_i of Hanson (1970) had the highest number of the significant correlations ($\text{SM}_{sp} = 33$).

These research results implicated that none of the stability parameters could represent all stability parameters. Based on that, several stability parameters should be used to obtain a strong basis for choosing the most stable phenotype or the most stable genotypes in a certain phenotype. In the case of selecting one parameter of stability, however, D^2_i of Hanson (1970) could be considered to be chosen. This suggestion was in contrary with research result of Temesgen et al. (2015). Choosing D^2_i of Hanson (1970) as parameter of stability based on the *saepe modi* (Table 1, $\text{SM}_{sp} = 33$) was entirely different with other selecting methods based which wa based on the prediction of the nature of $G \times E$ interaction and the need of a simple statistical method (Freeman, 1973; Becker, 1981; Lin et al., 1986; St.Clair and Kleinschmit, 1986; Becker and Leon, 1988; Bacusmo et al., 1988; Magari and Kang, 1993; Piepho, 1994; Ferreira et al., 2006; Souza et al., 2007; Mitrovic et al., 2011; Nascimento et al., 2013; Syukur et al., 2014; Balakrishnan et al., 2016).

Table 1. Correlation among parameters of stability in branch rust incidence, leaf rust incidence, and leaf rust severity

| Parameter | Variable | Variance | | | | | Regression | | | | | | | | Nonparametric | | | |
|----------------|----------|----------------------|----------------------------|-----------------|---------------|---------------|------------------------------|---------------------------|----------------------------|--------------------------|--------------------------|---------------|------------|-------------|----------------------|-----------------------|-------------|-----------|
| | | Author and parameter | | | | | Author and parameter | | | | | | | | Author and parameter | | | |
| | | Roemer (1917) | Plaisted and Peters (1959) | Plaisted (1960) | Wricke (1962) | Shukla (1972) | Francis and Kanneberg (1978) | Finlay and Wilkins (1963) | Eberhart and Russel (1966) | Perkins and Jinks (1968) | Perkins and Jinks (1968) | Hanson (1970) | Tai (1971) | Tai (1971) | Pinthus (1973) | Linn and Binns (1978) | Kang (1993) | |
| | | s^2_i | θ_i | $\theta_{(i)}$ | W^2_i | σ^2_i | cv_i | b_i | δ^2_i | β_i | ψ^2_i | D_i^2 | α_i | λ_i | r^2 | P_i | κ_i | SM_{sp} |
| s^2 | BRI | 1 | 0.541 | -0.541 | 0.541 | 0.541 | 0.593 | 0.988 | 0.999 | 0.987 | 0.259 | 0.765 | 0.988 | 0.408 | -0.261 | 0.156 | 0.484 | 5 |
| | | | ns | ns | ns | ns | ns | ** | ** | ** | ns | * | ** | ns | ns | ns | ns | |
| | LRI | 1 | 0.484 | -0.484 | 0.484 | 0.457 | 0.767 | 0.942 | 1.000 | 0.941 | 0.999 | 0.703 | 0.940 | 0.465 | -0.415 | 0.175 | 0.300 | 6 |
| θ_i | LRS | 1 | 0.886 | -0.887 | 0.886 | 0.886 | 0.987 | 0.902 | 0.997 | 0.902 | 0.905 | 0.979 | 0.902 | 0.903 | 0.979 | 0.097 | 0.610 | 13 |
| | | | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ns | ns | |
| | BRI | | 1 | -1.000 | 1.000 | 1.000 | 0.490 | 0.402 | 0.546 | 0.400 | 0.870 | 0.956 | 0.403 | 0.965 | -0.925 | 0.391 | 0.782 | 8 |
| $\theta_{(i)}$ | LRI | | 1 | -1.000 | 1.000 | 1.000 | 0.848 | 0.162 | 0.495 | 0.160 | 0.993 | 0.963 | 0.158 | 0.997 | -0.993 | 0.887 | 0.811 | 10 |
| | | | | ** | ** | ** | * | ns | ns | ns | ** | ** | ns | ** | * | ** | * | |
| | LRS | | 1 | -1.000 | 1.000 | 1.000 | 0.898 | 0.600 | 0.866 | 0.600 | 0.965 | 0.963 | 0.600 | -0.992 | 0.963 | 0.377 | 0.702 | 10 |
| W^2_i | BRI | | | 1 | -1.000 | -1.000 | -0.490 | -0.402 | -0.546 | 0.400 | -0.870 | -0.956 | -0.403 | -0.965 | 0.925 | -0.391 | -0.782 | 8 |
| | | | | | ** | ** | ns | ns | ns | ns | * | ** | ns | ** | ** | ns | * | |
| | LRI | | | 1 | -1.000 | -1.000 | -0.848 | -0.162 | -0.495 | -0.160 | -0.993 | -0.963 | -0.158 | -0.997 | 0.993 | -0.887 | -0.811 | 10 |
| σ^2_i | LRS | | | 1 | -1.000 | -1.000 | -0.898 | -0.600 | -0.866 | -0.600 | -0.965 | -0.963 | -0.600 | 0.992 | -0.963 | -0.377 | -0.701 | 10 |
| | | | | | ** | ** | ** | ns | * | ns | ** | ** | ns | ** | ** | ns | ns | |
| | BRI | | | | 1 | 1.000 | 0.490 | 0.402 | 0.546 | 0.400 | 0.870 | 0.956 | 0.403 | 0.965 | -0.925 | 0.391 | 0.782 | 8 |
| σ^2_i | LRI | | | | 1 | 1.000 | 0.848 | 0.162 | 0.495 | 0.160 | 0.993 | 0.963 | 0.158 | 0.997 | -0.993 | 0.887 | 0.811 | 10 |
| | | | | | | ** | * | ns | ns | ns | ** | ** | ns | ** | ** | ** | * | |
| | LRS | | | | 1 | 1.000 | 0.898 | 0.600 | 0.866 | 0.600 | 0.965 | 0.963 | 0.600 | 0.992 | 0.963 | 0.377 | 0.702 | 10 |
| | | | | | | ** | ** | ns | * | ns | ** | ** | ns | ** | ** | ns | ns | |

| | | | | | | | | | | | | | |
|-----------------------------|-----|---|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|--------------|-------------|----|
| cv _i | BRI | 1 | 0.553 ns | 0.620 ns | 0.553 ns | 0.609 ns | 0.583 ns | 0.554 ns | 0.570 ns | 0.570 ns | 0.878 ** | 0.861 * | 2 |
| | LRI | 1 | 0.540 ns | 0.772 * | 0.538 ns | 0.825 * | 0.927 ** | 0.536 ns | 0.831 * | -0.805 * | 0.750 ns | 0.766 * | 11 |
| | LRS | 1 | 0.869 ** | 0.981 ** | 0.869 * | 0.903 ** | 0.976 ** | 0.869 * | 0.908 ** | 0.976 ** | 0.220 ns | 0.716 ns | 13 |
| b _i | BRI | | 1 | 0.986 ** | 1.000 ** | 0.118 ** | 0.654 ** | 1.000 ** | 0.264 ns | -0.111 ns | 0.096 ns | 0.380 ns | 6 |
| | LRI | | 1 | 0.937 ** | 1.000 ** | 0.134 ns | 0.423 ns | 1.000 ** | 0.141 ns | -0.086 ns | -0.143 ns | 0.028 ns | 4 |
| | LRS | | 1 | 0.917 ** | 1.000 ** | 0.665 ns | 0.794 * | 1.000 ** | 0.637 ns | 0.794 * | -0.184 ns | 0.400 ns | 7 |
| δ ² _i | BRI | | | 1 | 0.985 ** | 0.281 ns | 0.769 * | 0.986 ** | 0.423 ns | -0.276 ns | 0.167 ns | 0.504 ns | 5 |
| | LRI | | | 1 | 0.936 ** | 0.471 ns | 0.712 ns | 0.936 ** | 0.478 ns | -0.426 ns | 0.184 ns | 0.301 ns | 5 |
| | LRS | | | 1 | 0.917 ** | 0.903 ** | 0.968 ** | 0.917 ** | 0.892 ** | 0.952 ** | 0.062 ns | 0.593 ns | 13 |
| β _i | BRI | | | | 1 | 0.117 ns | 0.653 ns | 1.000 ** | 0.263 ns | -0.109 ns | 0.096 ns | 0.379 ns | 4 |
| | LRI | | | | 1 | 0.132 ns | 0.421 ns | 1.000 ** | 0.139 ns | -0.084 ns | -0.145 ns | 0.026 ns | 4 |
| | LRS | | | | 1 | 0.665 ns | 0.794 * | 1.000 ** | 0.637 ns | 0.794 * | -0.184 ns | 0.400 ns | 7 |
| ψ ² _i | BRI | | | | | 1 | 0.757 * | 0.120 ns | 0.969 ** | -0.973 ** | 0.665 ns | 0.841 * | 9 |
| | LRI | | | | | 1 | 0.949 ** | 0.130 ns | 0.999 ** | -0.998 ** | 0.883 ** | 0.765 * | 11 |
| | LRS | | | | | 1 | 0.958 ** | 0.665 ns | 0.991 ** | 0.958 ** | 0.267 ns | 0.669 ns | 10 |
| D _i ² | BRI | | | | | | 1 | 0.655 ns | 0.882 ** | -0.800 * | 0.354 ns | 0.769 * | 11 |
| | LRI | | | | | | 1 | 0.419 ns | 0.955 ** | -0.936 ** | 0.775 * | 0.752 ns | 9 |
| | LRS | | | | | | 1 | 0.794 * | 0.969 ** | 1.000 ** | 0.224 ns | 0.668 ns | 13 |
| α _i | BRI | | | | | | | 1 | 0.265 ns | -0.112 ns | 0.098 ns | 0.381 ns | 4 |
| | LRI | | | | | | | 1 | 0.137 ns | -0.082 ns | -0.147 ns | 0.024 ns | 4 |
| | LRS | | | | | | | 1 | 0.637 ns | 0.794 ns | -184 ns | 0.400 ns | 7 |

| | | | | | | | | | | | | | | | | | | | | |
|-------------|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----------|----------|---------|----|
| λ_i | BRI | | | | | | | | | | | | | | | ns | * | ns | ns | 8 |
| | | | | | | | | | | | | | | | | 1 | -0.982** | ns | * | |
| | LRI | | | | | | | | | | | | | | | 1 | -0.998** | 0.883** | 0.786* | 10 |
| | LRS | | | | | | | | | | | | | | | 1 | 0.969** | 0.327ns | 0.692ns | 10 |
| r_i^2 | BRI | | | | | | | | | | | | | | | | 1 | 0.550ns | 0.840* | 8 |
| | | | | | | | | | | | | | | | | | 1 | -0.895** | -0.789* | |
| | LRI | | | | | | | | | | | | | | | | 1 | 0.224ns | 0.668ns | 13 |
| P_i | BRI | | | | | | | | | | | | | | | | | 1 | 0.843* | 2 |
| | | | | | | | | | | | | | | | | | | 1 | 0.841* | |
| | LRS | | | | | | | | | | | | | | | | | 1 | 0.801* | 1 |
| κ_i | BRI | | | | | | | | | | | | | | | | | | 1 | 10 |
| | LRI | | | | | | | | | | | | | | | | | | 1 | 9 |
| | LRS | | | | | | | | | | | | | | | | | | 1 | 1 |
| SM_{sp} | Total | 24 | 28 | 28 | 28 | 28 | 26 | 17 | 23 | 15 | 30 | 33 | 15 | 28 | 31 | 12 | 20 | | | |

n = 28, BRI = branch rust incidence, LRI = leaf rust incidence, LRS = leaf rust severity, ns = not significant, * = significant at α 0.05 = 0.374, and ** = highly significant at α 0.01 = 0.478, SM_{sp} = number of frequency of parameter correlating significantly with others.

CONCLUSION

This result proved that none of the parameters of stability could represent all stability all parameters. If someone prefer to use one parameter of stability, it is suggested to use regression and deviation from regression (D^2_i) proposed by Hanson (1970). However, if a researcher needs to use many stability parameters, *Saepo modi* (SM_{sp}) could be considered to be used.

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